

**Amendments to the Specification**

Please amend the specification as follows:

**Please amend the paragraphs beginning on page 5, line 16, through page 6, line 18, as follows:**

Semiconductor manufacturing facilities generally use some version of the following complex overlay procedure to help determine the magnitude of lens distortion independent of other sources of systematic overlay error. The technique has been simplified for illustration. See Analysis of image field placement deviations of a 5x microlithographic reduction lens, D. MacMillen, et. Al., SPIE Vol. 334, 78:89, 1982. Figures 2 and 3 show typical sets of overlay targets 300, including – one large or outer box 302 and one small or inner target box 304. Figure 1 shows a typical portion of a distortion test reticle 102 used in the prior art. It should be noted that the chrome target patterns on most reticles are 4 or 5 times larger as compared with the patterns they produce at the image plane, plane; this simply means modern steppers are reduction systems. Further, for purposes of discussion, it is assumed that the reticle pattern is geometrically perfect, (in practice, the absolute positions of features on the reticle can be measured and the resulting errors subtracted off). First, a wafer covered with photoresist is loaded onto the wafer stage and globally aligned. Next, the full-field image of the reticle, 102 in Figure 1 is exposed onto the resist-coated wafer 2102 in Figure 21. For purposes of illustration, we assume that the distortion test reticle consists of a 5 x 5 array of outer boxes evenly spaced a distance  $M \cdot P$ , across the reticle surface see Figure 1. It is typically assumed that the center of the optical system is virtually aberration free. See Analysis of image field placement deviations of a 5x microlithographic reduction lens, *supra*. With this assumption, the reticle, 102 in Figure 1 is now partially covered using the reticle blades, 1704 in Figure 17, in such a way that only a single target at the center of the reticle field, box 104, in Figure 1, is available for exposure. Next, the wafer stage is

moved in such a way as to align the center of the reticle pattern directly over the upper left hand corner of the printed 5 x 5 outer box array, wafer position 2400 2106, Figure 21. The stepper then exposes the image of the small target box onto the resist-coated wafer. If the stepper stage and optical system were truly perfect then the image of the small target box would fit perfectly inside the image of the larger target box, as illustrated in Figures 4, and 21, from the previous exposure.

**Please amend the paragraphs beginning on page 13, line 14, through page 16, line 8, as follows:**

Overlay error is referred to as overlay registration ~~include,~~ including registration error and pattern placement error, error; for our work here, we will simply use the term overlay error or error. For classification purposes, overlay error is typically divided into the following two categories: grid or inter-field and intra-field error. Intra-field error is the overlay error in placement within a projection field, or simply field, of a lithographic projection system. Inter-field error is the overlay error from field to field on the wafer. The physical sources of these errors are generally distinct; inter-field error is due to imaging objective aberrations or possibly scanning dynamics while intra-field errors are due to the wafer alignment system and the wafer stage. The focus of this invention is determination of intra-field error.

In order to measure overlay error using conventional optical metrology tools, special alignment attributes or overlay target patterns, such as the ones shown in Figure 14, are printed or imaged onto a properly designed recording media using a photolithographic imaging system such as the one illustrated in Figure 17. Here recording media is meant to include: positive or negative photoresist, optically activated liquid crystals, CCD or diode imaging arrays, and photographic film. There are many different kinds of alignment attributes including, box-in-box 1402, frame-in-frame 1404 as shown in Figure 14, as well as gratings, verniers, and electrical test structures. See Automated Electrical Measurements of Registration Errors in Step

and Repeat Optical Lithography systems, T. Hasan, et. Al., IEEE Transactions on Electron Devices, Vol. ED-27, No. 12, 2304:2312, December, 1980; Capacitor Circuit Structure For Determining Overlay Error, K. Tzeng, et. Al., US Patent 6143621, 2000; Overlay Alignment Measurement of Wafers, N. Bareket, US Patent 607925, 2000. The present invention applies to photolithographic steppers, scanners, e-beam systems, EUV and x-ray imaging systems. See Mix-And-Match: A necessary Choice, *supra*; Reduction imaging at 14nm using multilayer-coated optics: Printing of features smaller than 0.1 micron, J. Bjorkholm, et. Al., Journal Vacuum Science and Technology, B 8(6), 1509:1513, Nov/Dec 1990; Development of XUV projection lithography at 60-80 nm, B. Newnam, et. Al., SPIE vol. 1671, 419:436, 1992; Optical Lithography – Thirty years and three orders of magnitude, J. Bruning, SPIE Vol. 3051, 14:27, 1997. Figure 28 shows a typical vector plot of overlay error measured with a commercial overlay tool using box-in-box structures. In some cases the overlay error can be measured using special in-situ exposure tool metrology. See Matching Management of multiple wafer steppers using a stable standard and a matching simulator, M. Van den Brink, et. Al., SPIE VOL. 1087, 218:232, 1989. Vector displacement plots like these illustrated in Figure 28 give a visual description of the direction, magnitude, and location of overlay error, and are mathematically separated into components using variety of regression routines; Figures 28- 30 are a schematic of this while See Analysis of overlay distortion patterns, J. Armitage, J. Kirk, SPIE Vol. 921, 207:221, 1988 contains numerous examples. Many commercial software packages exist (Monolith, See A Computer Aided Engineering Workstation for registration control, *supra.*, Klass II; See Lens Matching and Distortion testing in a multi-stepper, stepper, sub-micron environment, A.Yost, et. al., SPIE Vol. 1087, 233:244, 1989) that model and statistically determine the relative magnitude of the systematic and random inter-field and intra-field error components for the purpose of process control and exposure tool set-up. Once the inter-field and intra-field overlay data is analyzed the

results are used to adjust the calibration constants and absolute position of the reticle stage, wafer handling stage and projection lens system to improve pattern alignment.

#### Preferred Embodiment

A simple and accurate methodology that allows for the extraction of lens distortion placement error excluding total translation, rotation, orthogonality and x and y scale error and is mathematically decoupled from stage error is described. Figure 34 illustrates the methodology in terms of a process flow diagram. First, in block 3402, a wafer is provided; wafer alignment marks are not required, a bare wafer can be used. Next, in block-3402 3404, the wafer is coated with resist and loaded onto the projection imaging system or machine. Then in block 3406, a reticle pattern such as illustrated in Figure 20, including a two dimensional array of box structures or targets of various sizes, see Figure 20A, is loaded into the machine's reticle management system and aligned to the reticle table. The reticle pattern be, for example,  $N_x \times N_y$  array of overlay groups as shown in Figure 20A with a portion of the whole  $N_x \times N_y$  array being schematically shown in figure 20.

**Please amend the paragraph on page 17, lines 13-14, as follows:**

Then in block 3416 we reconstruct the overlay measurements that are used to produce the lens distortion map.

**Please amend the paragraph on page 21, lines 7-15, as follows:**

In another embodiment, if it is believed or there is evidence that the wafer stage and reticle alignment system are extremely accurate and repeatable ~~for~~ (for example if the accuracy and repeatability  $\sim$  overlay metrology tool accuracy and repeatability), then all stage positioning and yaw errors  $(Tx_1, Ty_1, q_1), \dots (Tx_4, Ty_4, q_4)$  can be set to zero in equations 5-8. Not solving for the T's and q's

allows determining the intra-field distortion uniquely to within an overall translation. That is, a unique solution that includes field rotation, orthogonality, and x and y scale is obtained if the constraints of equation 9 and equation 10 through equations 14 and 15 are imposed and then calculate (dxf, dyf) using the resulting Tx, Ty values and setting  $q=q_0=s_x=s_y=0$  in equations 20 and 21.

**Please amend the paragraph on page 29, lines 15-23, as follows:**

In another embodiment, if ~~its~~ it is believed, or there is evidence, that the wafer stage and reticle alignment system are extremely accurate and repeatable, for example if the accuracy and repeatability  $\sim$  overlay metrology tool accuracy / repeatability, then all stage positioning and yaw errors (Tx1,Ty1,q1), . . . (Tx6,Ty6,q6) can be set to zero in equations 27-32. Not solving for the T's and q's allows determining the intra-field distortion uniquely to within an overall translation. That is, a unique solution is obtained that includes field rotation and overall scale if the constraints of equation 33 and equation 34 through equations 37 and 38 are imposed and then calculate (dxf, dyf) using the resulting Tx, Ty values and setting  $q=s=0$  in equations 41 and 42.

**Please amend the paragraph beginning on page 32, lines 5-21, as follows:**

A variation of the first two embodiments that allows the user to extract the repeatable part of the intra-field distortion with a minimum number of exposed fields and overlay metrology is described. Below,  $E_0$  is the E-zero or minimum exposure dose required for a large, i.e. 200 micron at wafer, open area pattern on the reticle to become fully developed, or cleared in the case of positive resist. Figure 34A illustrates a process flow diagram where in blocks 3442, 3444 and 3446, the overlay target reticle and resist coated wafer are loaded into the projection imaging tool, or machine, as described above. Next in blocks 3448 and 3450, instead of exposing

each field with a single scanning or exposing action, the machine is programmed to expose each field at a multiplicity of lower doses. So if  $a \cdot E_o$  ( $a > 1$ ) is the required dose at the wafer to completely expose a single field with a single exposing action, we expose the field  $N$  times at a dose of  $a \cdot E_o / N$ , where  $N$  is some predetermined number, typically 20. Within these  $N$  exposures the wafer stage is not moved to another field position, a single field is exposed  $N$  times. In the preferred embodiment, this process is repeated 3 more times for the other fields. The result of this procedure is to average out the scanning non-repeatability by an amount proportional to  $N$  (parameterized as  $b \cdot M$ ). The exact configuration of the resist (novolac, chemically amplified, resist manufacturer, processing conditions) determines whether  $b = 1$  or is  $< 1$ .

**Please amend the paragraphs beginning on page 33, lines 1-21, as follows:**

Then in blocks 3452, 3454, and 3456 the wafer is developed and the overlay targets ~~and~~ are measured and a lens distortion map constructed as described above in connection with Figure 34.

In another variation of the first two embodiments, multiple exposing actions are performed to average out the effect of non-repeatability, but now the overlay reticle, for example the reticle of Figure 20, has a partially reflecting dielectric coating either on ~~it's~~ its non-chrome or possibly chrome coated (machine optical object plane) surface see Figure 20C. For example, a 95% reflecting dielectric coating applied to the overlay reticle means that if there are 20 exposure sequences, at a dose of  $E_o$  each, the net effect is to expose the wafer with a dose of  $2 \cdot E_o$  and to have effectively averaged over as many as 20 exposures. The advantage of this technique is that it is not limited by the machine's ability to do sub- $E_o$  exposures. A further advantage of this technique is that since the exposure doses can be made at the same dose as used in production runs, the dynamics of

the scanner movement during the measurement sequence will be the same and therefore the intra-field error measured under identical operating conditions. Thus, if the production dose is  $a \cdot E_0$ , the overlay reticle has a coating that reflects a fraction  $R$  of light incident on it, then the number of exposures ( $N$ ) required to get a dose of  $b \cdot E_0$  on the measurement wafer is:

$$N = 1 + \text{floor}(b/(a \cdot (1-R))) \quad (\text{eq 43})$$

and

$\text{floor}(x)$  = integer part of the real number  $x$ .

**Please amend the paragraph on page 34, lines 9-20, as follows:**

The techniques described above have been mainly described with respect to alignment attributes that are in the form of a box in box or frame in frame pattern as shown in Figure 14. Other alignment attributes such as gratings can be used. See U.S. Patent 6,079,256 - Overlay Alignment Measurement of Wafer, *supra*, and Figure 1b, wafer alignment marks See Matching Management of multiple wafer steppers using a stable standard and a matching simulator, *supra*, van der Pauw resistors. See Automated Electrical Measurements of Registration Errors in Step and Repeat Optical Lithography systems, *supra*, vernier pairs; See Method of Measuring Bias and Edge overlay error for sub 0.5 micron Ground Rules, C. Ausschnitt, et. Al., US Patent 5757507, 1998, capacitor structures. See Capacitor Circuit Structor For Determining Overlay Error, *supra* could be used instead. In general, any alignment attribute that can be used by an overlay metrology tool for measuring offsets can be utilized by the techniques described.

**Please amend the paragraph beginning on page 45, line 5, through page 46, line 3, as follows:**

The techniques have been mainly described with respect to it's their application on the projection imaging tools such as photolithographic stepper

systems. See Direct-referencing automatic two-points reticle-to-wafer alignment using a projection column servo system, *supra*; New 0.54 Aperture I-Line Wafer Stepper With Field by Field Leveling Combined with Global Alignment, M. Van den Brink, B. Katz, S. Wittekoek, SPIE Vol. 1463, 709:724, 1991; Projection optical system for use in precise copy, T. Sato, et. Al., US Patent 4861148, 1989, and photolithographic scanners systems. See Micrascan (TM) III performance of a third generation, catadioptric step and scan lithographic tool, D. Cote, et. Al., SPIE Vol. 3051, 806:816, 1997; ArF Step And Scan Exposure System For 0.15 Micron and 0.13 micron Technology Node, J. Mulken, et. Al., SPIE Conference on Optical Microlithography XII, 506:521, March, 1999; 0.7 NA DUV step and Scan system for 150nm Imaging with Improved Overlay, ~~*supra*~~ *supra*, most commonly used in semiconductor manufacturing today. The techniques can be applied to other projection imaging tools such as contact or proximity printers. See Optical Lithography – Thirty years and three orders of magnitude, *supra*, 2-dimensional scanners; See Large-area, High-throughout, High-Resolution Projection Imaging System, K. Jain, US Patent 5285236, 1994, Optical Lithography – Thirty years and three orders of magnitude, *supra*, office copy machines, and next generation lithography (ngl) systems such as XUV. See Development of XUV projection lithography at 60-80 nm, *supra*, SCALPEL, EUV (Extreme Ultra Violet); See Reduction imaging at 14nm using multilayer-coated optics: Printing of features smaller than 0.1 micron ef 53, *supra*, IPL (Ion Projection Lithography), and EPL (electron projection lithography). See Mix-And-Match: A necessary Choice, *supra*. In addition, the techniques can be applied to a lithographic projection system used in an electron beam imaging system, or a direct write tool, or an x-ray imaging system.